

Use of integrated optical waveguide probes as an alternative to fiber probes for sensing of light backscattered from small volumes

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Summary

We show that for light collection from thin samples, integrated probes can present a higher efficiency than conventional fiber probes, despite having a smaller collection area. Simulation results are validated by experiments.

Introduction

Fiber-optic probes are widely used today in optical techniques such as *in vivo* Raman spectroscopy and fluorescence spectroscopy, where probes with small dimensions and high flexibility are needed. However, the use of fibers is not always advantageous since they can introduce noise and signal distortions (dependent on fiber length). For example, when the signal is composed of different wavelengths, it can be distorted due to the wavelength-dependent transmission of the fiber; furthermore, when extremely weak Raman signals need to be detected, the luminescence and Raman emission induced in the collection fiber by the excitation light can severely deteriorate the signal-to-noise ratio. To partially overcome the latter problem most Raman probes make use of distinct fibers for guiding the excitation light and for signal collection, respectively [1, 2].

In this work we investigate the use of integrated probes as alternatives to fiber probes for specific applications. Integrated probes may present several advantages over fibers, such as polarization maintenance and reduced propagation length. They are, in general, less efficient due to their small collection area. We demonstrate, however, that waveguide probes can be at least as efficient as fiber probes in the case of very thin samples, while in addition providing higher lateral resolution. The need to perform measurements on thin samples is common to many applications, for example Raman spectroscopy of the skin [1].

Model and experiments

We have developed an analytical model for integrated waveguide probes by extending previous models [3-5] for fiber probes. Different probe geometries have been compared using a figure of merit S (initially introduced by Schwab et al. [5]), a quantity that does not depend on the sample's scattering properties or on the available optical power but only on the geometry of the probe and the overlap volume between excitation and acceptance cones. In particular (b-c), comparing a dual waveguide probe with a dual fiber probe, shows S as a function of the distance d between the excitation and collection channels, for three different values of the sample thickness t . The results suggest that waveguide probes can have even higher efficiencies than conventional fiber probes in case of thin samples and for small detector-to-source distances d (see Fig. 1 (a)). The lateral resolution achievable with a fiber probe depends on the core diameter, which is typically much larger than that of an integrated waveguide.

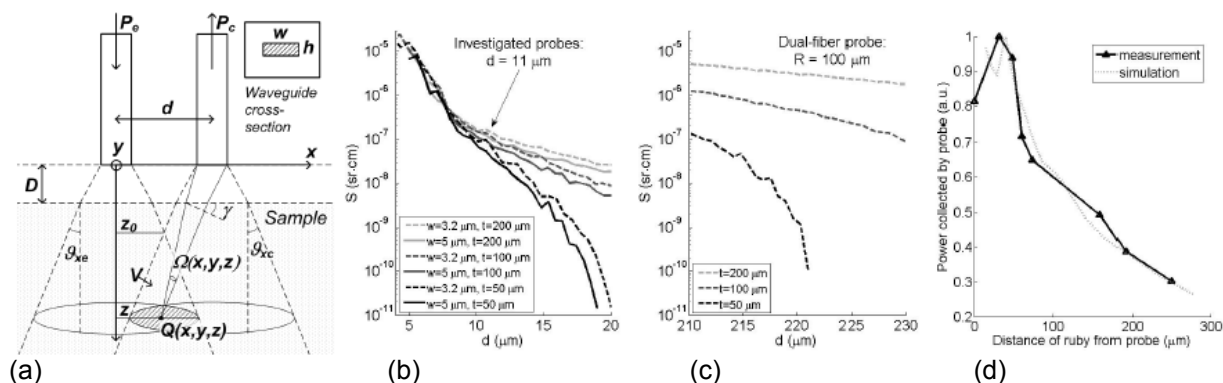


Fig. 1. (a) Schematic of a dual-waveguide probe; figure of merit S for sample thicknesses $t = 50, 100$, and $200\mu\text{m}$ for (b) integrated probes and (c) a conventional fiber probe with core radius of $100\mu\text{m}$; (d) simulation and measurement of fluorescence from a ruby rod positioned at varying distance from the probe.

In Fig. 1(c) the minimum distance d between excitation and collection fibers is $210\mu\text{m}$ because of the radii of excitation and collection fiber each being $100\mu\text{m}$, while for the integrated waveguides in Fig. 1(b) this distance is much smaller (depending on waveguide width w).

The probe model was applied to collecting fluorescence from a ruby rod. Figure 1(d) shows the results of both the simulation and the measurement of the fluorescence signal at 692.9nm and 694.3nm wavelength from a ruby rod, using a probe with $d = 11\mu\text{m}$ and an excitation wavelength of 532nm . The figure shows the collected intensity at different probe-to-sample distances D . As the ruby rod is moved further away from the probe the detected signal initially increases, reaching a maximum, and then decreases. The good agreement found between measurement and simulation validates our analytical model.

Conclusions

Our study shows that for the collection of light backscattered from samples under investigation waveguide probes can achieve higher resolution than conventional fiber probes while having the same or slightly higher collection efficiency in case of thin samples. The higher resolution is mainly due to the fact that excitation and collection waveguides can be placed very close to each other with a gap of just a few micrometers. In this way, despite the small collection area compared to that of a conventional fiber, it is still possible to have a good overlap between the excitation and collection cones and, therefore, high efficiency. The mathematical model used to draw these conclusions has been validated by our experimental results.

References

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